Sample Processor for Life on Icy Worlds (SPLIce): Monolithic Manifold-Based System to Recover, Prepare, and Deliver Samples and Standards to Instrumentation Suites for Ocean World Life-Search Missions

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Introduction: A claim of life detection on one of the solar system's icy ocean worlds would necessitate extraordinarily convincing evidence. Limited energy availability in the oceans of such bodies as Europa and Enceladus argues for microbes as most probable among possible life forms,[1] but evidence of their existence in the surface layers of an icy moon or in a frozen plume ejected into space could take various forms, pointing to instrumentation suites as a preferred means to detect diverse molecular and morphological life indicators. Multiple disparate categories of positive detections could provide truly convincing evidence from samples that may be only a few microliters.

SPLIce's Foundation. Teams led by NASA's Ames Research Center have developed and operated numerous small, live-biology and astrobiology science payloads in space over two decades.[2-5] Since 2016, we have adapted and augmented their biological sample-handling systems to create compact, robust search-for-life fluidic processors designed to function after a decade or more in transit, in environments with very little gravity and lots of radiation: up to 100's of kilorads.

Implementation: SPLIce comprises a monolithic, multilayer manifold—effectively, a multilayer microfluidic circuit board—that fuses three or more autoclavable thermoplastic layers; the manifold fastens to a thin metal baseplate for rigidity, thermal uniformity, and mechanical integration. Fluidic microchannels at layer interfaces, with cross sectional areas of 0.13 or 0.8 mm^2, carry liquids and gases. Vias connect microchannels to one another and to a range of miniature components: valves (magnetically latching, spring-closed, hermetic); pumps (peristaltic, metering); bubble traps and concentrators (employing hydrophobic membranes); sensors; compartments to house dried reagents on porous polymer monoliths; flow-control orifices; and connectors to external tubing. They support sample volumes from a few µL to several mL.

Functionality. The SPLIce monolithic manifold processes and distributes blanks, standards, controls, and samples, integrating a wide range of fluidic functions under autonomous control: retrieval of (particle-laden) liquid samples from a sample-collection chamber; onboard storage of dehydrated reagents, including fluorescent labeling compounds and pH buffers; integrated pressure, pH, redox, and ionic conductivity sensors; filtration, retention, and staining of insoluble particles for characterization by microscopy; dilution or vacuum-enabled concentration of samples, tailoring concentrations to instrument detection capabilities; removal of gas bubbles from fluid; directional flow control; active multipath routing; and metered microvolume pumping.

Tailoring to the application. The SPLIce family of manifolds has ~10 variants (Figure 1 shows two), tailored to support one or multiple analytical instruments and sensors, including capillary electrophoresis with laser-induced fluorescence detection;[6] mass spectroscopy detection of samples following either derivatization and separation by gas chromatography,[7] or separation by capillary electrophoresis;[8] a suite of electrochemical sensors, featuring multiple ion-selective electrodes;[9] multi-wavelength fluorescence-and-bright-field microscopy;[10] and nanopore analysis, including sequencing.[11]

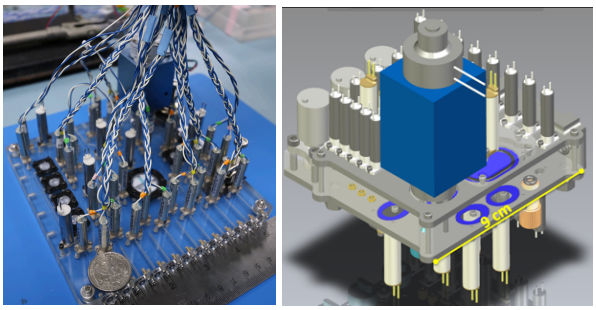

Figure 1. Left: *SPLIce 2.0 prototype with integrated hardware.* ***Right:*** *SPLIce 3.2 solid model. Large blue block in foreground is a metering pump; the numerous cylinders are valves of various types. This design fits within the 10x10 cm x,y constraints of a multi-U cubesat format.*

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